

AIRCRAFT SURVIVABILITY



SURVIVABILITY 2000

On A Heading For Success!

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About the cover:
The new century coincides with new leadership for the JTCG/AS under Mr. James F. O'Bryon. See his article, "Looking to the Future of the JTCG/AS."

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Editor's Notes

Our focus for this issue of *Aircraft Survivability* is aircraft vulnerability reduction. Included are four articles that report on JTCG/AS-sponsored projects related to aircraft vulnerability reduction.

In addition, you will find two articles on the survivability symposium sponsored by the National Defense Industrial Association (NDIA) and held annually in Monterey, California, at the Naval Postgraduate School. This year's event took place 16–18 November 1999 with the theme, "Aircraft Survivability 1999: Challenges for the New Millennium." In the first article, VADM John Lockard summarizes his keynote address, "Supporting the Warfighter...Delivering 21st Century Aviation Solutions Enabling Dominance from the Sea." The second article provides an informative report on the symposium by its chairman, Mr. Dave Hall.

In the last issue of *Aircraft Survivability*, we reported the transfer of sponsorship for the JTCG/AS within the Department of Defense to the Office of the Director, Operational Test and Evaluation/Live Fire Test, Mr. James F. O'Bryon. In this issue, Mr. O'Bryon presents his insights and vision in the article titled "Looking to the Future of the JTCG/AS."

By the time you read this, the JTCG/AS will have completed its comprehensive study on the man-portable air defense systems (MANPADS) missile threat. Titled *MANPADS Threat to Aircraft: A Vulnerability Perspective*, the report responds to an OSD tasking to the JTCG/AS to investigate whether viable opportunities exist for increasing aircraft survivability against MANPADS through improved vulnerability reduction design techniques or technologies.

The report represents the work of many individuals over the last 18 months. Mr. Greg Czarnecki from the Safety and Survivability Office of the 46th Test Wing at Wright-Patterson Air Force Base, Ohio, was the project leader. Mr. Al Wearner from the Naval Air Warfare Center (NAWC), China Lake, California, was the project coleader. Others, including Dr. Kristina Langer, Dr. Jeff Calcaterra, and Lt. Stephanie Masoni from Wright-Patterson made significant contributions. Substantial work was also performed, under contract, by the Survivability/Vulnerability Information Analysis Center (SURVIAC) team led by Mr. Kevin Crosthwaite. Other SURVIAC team members were Mr. Gerry Bennett, Mr.

Dave Legg, Ms. Donna Egner, and Ms. Linda Ryan.

The MANPADS report has spawned related efforts, including a MANPADS Joint Test and Evaluation (JT&E) nomination called JASMAN (for Joint Aircraft Survivability to MANPADS), which is currently being prepared for submittal through Air Force channels. Another significant effort to begin this fiscal year will be executed under a contract award to The Boeing Company to conduct a multitask examination of innovative ways to reduce aircraft vulnerability to MANPADS. Funded by the JTCG/AS, this contract is the result of a Broad Agency Announcement (BAA) issued last year. In addition to JTCG/AS-funded research on reducing aircraft vulnerability to MANPADS, the Joint Live Fire office under Mr. O'Bryon is sponsoring a series of coordinated MANPADS tests. The JTCG/AS has formed a joint ad hoc technical committee to help coordinate these efforts, ensure that service interests are represented, and leverage related work within the services.

Next, I draw your attention to the article on space survivability by Dr. Joel Williamsen of the University of Denver Research Institute, Denver, Colorado and Dr. Jeff Calcaterra from the 46th Test Wing at Wright-Patterson AFB, Ohio. A topic of interest here is assessing the application of traditional aircraft survivability analyses tools to space platforms.

Finally, our survivability pioneer selection for this issue is Mr. Dale Atkinson. And we are pleased to have the article about Dale's career authored by Distinguished Professor Bob Ball, who has known and worked with Dale for many years.

As always, we welcome your feedback. Our E-mail address is on the inside front cover.



Looking to the Future of

by Mr. James F. O'Bryon

I welcome this unique opportunity to share with the readers of *Aircraft Survivability* some personal thoughts regarding recent events in the Pentagon and their implications on the Joint Technical Coordinating Group on Aircraft Survivability.

The recent reorganization of some of the test and evaluation functions within the Office of the Secretary of Defense (OSD) has had a significant and positive impact on the discipline of survivability within the Department of Defense (DoD). The disestablishment of the office of the Director, Test Systems Engineering and Evaluation (DTSE&E) and the subsequent reassignment of several functions formerly administered by the DTSE&E provides a unique opportunity to bring together many of the relevant non-nuclear survivability/vulnerability/lethality activities in OSD. Among the actions was to move the Joint Technical Coordinating Group on Aircraft Survivability (JTTCG/AS) and Munitions Effectiveness (JTTCG/ME) to the Office of the Director, Operational Test and Evaluation (DOT&E), with management oversight from the Deputy Director, OT&E/Live Fire Test.

This, in a way, is a homecoming for these programs. They had been under the oversight of the LFT&E office prior to the passage of the Federal Acquisition Streamlining Act, which moved oversight of the LFT&E from the USD(A&T), OSD to the DOT&E some five years ago.

This move has also helped to fulfill some of the recommendations of the National Academy of Sciences study of LFT&E Vulnerability Assessment of Aircraft, published in 1993. Among other things it recommended expanding the charter of the LFT&E program beyond simply testing, to include vulnerability analyses methodologies as well. This can now become a reality.

Having oversight of the JTTCGs within the DOT&E will also help to assure that overall platform survivability assessment, whether aircraft, tank, or ship is done in the overall context of susceptibility to attack, vulnerability from attack, and overall combat effectiveness as the legislation establishing LFT&E requires.

Our goal now is to set the proper vision and priorities, strengthen the management of the JTTCGs, and support their programs and budgets at the highest levels. We must also assure that the models and simulations being promulgated by the JTTCGs are indeed representative of reality, and if not, alert the communities now relying on them of their limitations and to correct those that are flawed. Another issue which will require much more JTTCG attention, is the growing number of helicopters, their numerous upgrades, and changing missions and threats. In fact, at this point, there are more different helicopter LFT&E programs (12) than fixed wing LFT&E programs (8), plus the V-22, which is a combination of both. I would like to see an active JTTCG/AS Operational Users Group (OUG) to assure that the JTTCG/AS keeps a constant eye on its end-consumer—the warfighter.

Combat aircraft and the weapons and equipment we place on these aircraft consume nearly 53 percent of the entire DoD procurement budget. Aircraft are clearly an important (and expensive) commodity. As we continue to build aircraft—some of whose costs exceed their weight in pure gold—we must be about realistic testing through our Live Fire Test program, and for fielded systems, the Joint Live Fire Test program. Realistic Operational Testing will also provide added information vital to the generation of their methodologies.

We also need to further invigorate the Survivability/Vulnerability Information Analysis Center (SURVIAC) to not only capture combat data and LFT & JLF data, but also accident/incident data, which would also serve the aircraft design community.

As we look to the future, we must begin to look seriously at not only ballistic threats but also other less traditional, but nonetheless important, directed energy threats. Electronic miniaturization, fly-by-wire aircraft,

the JTCG/AS

composite structures, high g-maneuvering aircraft, the growing reliance on UAVs, all present growing challenges to the JTCG/AS community.

Another unique opportunity for the JTCG/AS organization to serve the nation is in its activities examining not only military aircraft vulnerability, but also commercial aircraft vulnerability, to terrorist activity.

The various other ongoing activities of the Live Fire Test Office, including serving as Secretariat of the Target Interaction Lethality Vulnerability (TILV) activity providing a venue for the Services to assemble and prioritize their V/L 6.1-6.3 investments into a TILV Master Plan—the Accelerated Strategic Computing Initiative (ASCI) LFT&E Modeling and Simulation initiative with the Department of Energy, the Joint Live Fire Test Program, and sponsorship of periodic Lessons Learned workshops will all serve the overall survivability community.

In fact, let me take this opportunity to invite the readers of this magazine to attend our National Live Fire Test and Evaluation Conference, May 8-12, 2000 at the University of Texas at Austin.

Again, I invite all members of the DoD Vulnerability/Survivability community—both inside and outside of government—to join with us and make the JTCG/AS all that it can be. I look forward to working with you. ■



Jim O'Bryon
Deputy Director, Operational Test
& Evaluation, Live Fire Testing

National Live Fire Test & Evaluation (LFT&E) Conference

8-12 May 2000

University of Texas

Austin, TX

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Supporting the Warfighter...

by VADM John A. Lockard, USN



Vice Admiral John A. Lockard, U.S. Navy

Delivering 21st Century Aviation Solutions Enabling Dominance from the Sea

The following is a synopsis of the keynote address given by VADM John A. Lockard, Commander, Naval Air Systems Command, at the Aircraft Survivability Symposium in Monterey, California, 16-18 November 1999.

In the new millennium, we must ensure our future Navy and Marine Corps combat aircraft are designed for survivability with a systems solution—a balanced approach. The simplicity of design and ultimate success of some of our earlier combat aircraft provide valuable lessons that should not be lost.

While the A-4 Skyhawk I flew over Vietnam as a junior officer is certainly outdated today, the lessons we learned then in redundancy, vulnerability reduction, and simplicity should not be ignored. We must move from individual platform-specific solutions to integrated system solutions that capture the benefits provided from the coopera-

tive information flow inherent in Network Centric Warfare. The future challenges we must overcome will require *system solutions* and *integration* of diverse technology advancements.

Our survivability design must exhibit a robustness that is consistent with our transition to multimission aircraft. This multimission capability dictates an ability to face potential threats throughout the entire electromagnetic spectrum. Our robust design must also reflect the realities of maintaining our full force structure. Technology solutions must satisfy a threat-driven requirement and at the same time, must be affordable.

Opportunities for designing new platforms will be limited in the future. We will expect 30+ years of service life from our platforms, requiring built-in growth provisions and new system integration to respond to

the evolving threat. “Cost as an Independent Variable” and “Analysis of Alternative” studies must consider full life-cycle supportability costs, as well as initial procurement costs, to ensure we obtain the best value for our limited investment dollars.

For Naval Aviation to fulfill its mission of flexible response and dominant power projection, we need a balanced approach to survivability. Electronic signature reduction—combined with standoff jamming, electromagnetic countermeasures (ECM) to degrade threat effectiveness, and platform vulnerability reduction—provides an affordable, proven solution. Tactics, smart mission planning, and standoff weapons allow our strike forces to stay outside of lethal threat zones. Shifting the cost of stealth to precision-guided munitions provides high lethality with limited risk to aircrew making it an attractive tradeoff. Real-time Command, Control, Communications, Computers & Intelligence Surveillance and Reconnaissance (C4ISR) connectivity allows us to win the “Information War” and concentrate our striking force on the enemy’s most vulnerable defensive node. All of this drives us to a balanced approach as the most cost-effective solution to achieving our Navy’s primary objective of ***Dominant Power Projection...From the Sea.***

The 21st century U.S. Navy and Marine Corps must be equipped to exploit the vast array of information warfare assets in a real-time fashion. The concept of Network Centric Warfare will provide the warfighter with an unparalleled ability to concentrate firepower in the most effective way. We will keep our adversaries off balance by reacting to the changing battlefield inside their decision loop capabilities. Thus, real-time information in the cockpit will enhance our survivability.

The new millennium will undoubtedly bring unique challenges to our survivability design process. Our solutions will evolve as threat capabilities increase but we will strive to maintain the proper balance among susceptibility reduction, vulnerability reduction, and countermeasures. Survivability must be designed for today’s threat with adaptability for the undefined future where we may be faced with the threat of directed energy weapons and high-powered

lasers on the battlefield. Network Centric Warfare enablers will ensure our technological superiority is the deciding factor in this new environment. We must find the affordable system solution that provides us the ability to respond to any threat, in any environment, anytime and anywhere.

The true meaning of survivability is clear to our valiant young men and women who risk their lives daily when performing their missions. They want to be able to do their job time and again, returning safely with their equipment ready to answer the next call. We owe them no less! ■

About the Author

Vice Admiral Lockard serves as Commander of the Naval Air Systems Command, an organization of over 33,000 people located at ten major sites across the United States. VADM Lockard’s office phone number is 301.757.7825.

NDIA Aircraft Survivability 1999

Challenges for the New Millennium

by Mr. David H. Hall

The NDIA Combat Survivability Division symposium, held 16–18 November 1999, provided a forum for exchanging information and advancing ideas that would enhance aircraft combat survivability in the next century. The symposium examined issues and challenges to survivability posed by infrared (IR), electro-optical (EO) and radar guided (RF) missiles and nontraditional threat systems and the technological solutions to these challenges being pursued in new aircraft and subsystem designs.

Before delving into the sessions focusing on these areas, two service briefings were presented addressing aircraft survivability in the future. VADM John A. Lockard, Commander of the Naval Air Systems Command and Chairman of the Joint Aeronautical Commanders Group, presented a joint-Service view of aircraft survivability in the new millennium. VADM Lockard described the approach to survivability in current Navy and Marine Corps programs, and he predicted that a balanced approach to survivability would be required for new platforms to meet emerging threat challenges.

Mr. Terry Neighbor, Director of Plans and Programs at the Air Force Research Laboratory, presented Air Force science and technology initiatives in aircraft survivability. The Air Force science and technology investment strategy is dedicated to the timely discovery, development and integration of affordable warfighting technologies for our armed forces. The focus for the future will be in susceptibility reduction and low vulnerability technologies, as well as associated cost and performance improvements.

Colonel Jeffrey W. Eberhart, USAF, presented a special report on the air war in Operation ALLIED FORCE. Col Eberhart is Commander of the 31st Operations Group at Aviano Air Base in Italy. During Operation Allied Force, the 31st Expeditionary Wing conducted around-the-clock combat operations for 79

straight days as the largest wing in the history of both the U.S. Air Force and NATO. Only two aircraft were lost over Serbia (both pilots were quickly rescued) out of more than 9,000 sorties. Aircraft survivability was a major factor in this success, which included training, command and control, rules of engagement, aircraft technology, weapons, self-protection hardware, intelligence, and tempo management. An issue to be resolved in future conflicts of this nature is a need for combined operational orders, among the air assets of the various countries involved.

The symposium was divided into several sessions, each addressing different issues and challenges facing the survivability discipline. The issues addressed and summaries of the session results are presented below.

Meeting the EO/IR Threat

- What operational lessons have we learned from recent conflicts?
- How can pilot situational awareness of Man Portable Air Defense Systems (MANPADS) threats be improved?
- How effective are Infra-Red Countermeasures (IRCM) techniques?
- What can be done to reduce the loss of aircraft hit by MANPADS?

There was considerable interest in this session, particularly in the MANPADS threat. This interest was fueled in part by a MANPADS tutorial presented by Mr. Rodney Ratledge from the Missile and Space Intelligence Center (MSIC), Huntsville, Alabama, and the presence of the Defense Intelligence Agency (DIA)/MSIC IR threat system van, which provided excellent displays of MANPADS.

This session demonstrated that situational awareness is a critical, very difficult problem when dealing with EO/IR threat systems. Reactive IRCM techniques can be very effective, but only when employed at the appropriate time. A possible technique for making preemptive IRCM effective was described. The JTTCG/AS is developing solutions to ballistic vulnerability of aircraft to MANPADS threats; a hit by a MANPADS is not necessarily a kill if the aircraft is designed properly.

Countering the RF Missile Threat

- How effective are reduced signature aircraft in combat?
- What new electronic warfare (EW) technologies are applicable to low observable (LO) platforms?

The briefings in this session demonstrated the combat effectiveness and survivability of low signature aircraft, such as the B-2. The session also introduced and demonstrated the application of new EW technologies (such as towed decoys) to reduced signature aircraft. The session showed conclusively that electronic countermeasures (ECM) and reduced signatures are complementary in a combat environment. There are tactical operational implications of having LO aircraft operating in concert with conventional aircraft. These complications are felt primarily at the combat operations center, especially in multi-national conflicts. However, the benefits of using LO vehicles where appropriate outweigh those complications. The Army also demonstrated the effectiveness of RF signature reduction for vertical takeoff and landing (VTOL) aircraft in a low to moderate clutter environment.

Reconsidering Nontraditional Threats

Nontraditional threat systems include high-power microwaves, lasers, and other directed energy systems. This session addressed the following issues:

- How real are these threats? Can pilots detect their presence?
- What can be done about them?

Although the high-power microwave threat is still years in the future, it is nonetheless coming, and should be considered during the design process for advanced air vehicle systems. There appears to be limited ability on the part of aircrews to detect the presence of directed energy weapons before their effects are felt. The shielding of pilot's eyes with goggles and of weapon sensors is effective against low-energy lasers, but the optical shielding must be designed for very specific wavelengths. For high-energy systems, techniques are available to reduce the vulnerability of aircraft structures.

Service Perspectives on Future Survivability Challenges

A series of briefings by service requirements offices was intended to address the following issue:

- What are the service operational views on requirements for aircraft survivability?

BG Joseph Bergantz, Comanche Program Manager, described the Army's perspective. The MANPADS threat is seen as the primary evolving threat to Army aviation. Rear Admiral James Robb presented the Navy's view of survivability challenges for fixed and rotary wing aircraft and unmanned vehicles. The Navy's thrust is for a balanced approach to survivability among susceptibility reduction features, such as stealth, ECM, situational awareness, and vulnerability reduction. Mr. Harry Disbrow covered Air Force survivability concerns. Stealth, standoff, and suppression of enemy air defence(s) (SEAD) are the primary capabilities for Air Force survivability, with future emphasis on Destruction of Enemy Air Defenses (DEAD). BGen James Cartwright explained the Marine Corps' view of survivability requirements. These requirements are driven by a significant period of transformation for the Corps in developing the Operational Maneuver From the Sea (OMFTS) concept. Survivability is key in this transformation.

To summarize the disparate service views on survivability requirements, the Marine Corps concluded that aircraft programs should emphasize vulnerability reduction to provide the best survivability, whereas all other services opinions were weighted toward susceptibility reduction. For the Air Force, that meant stealth; for the Army, the emphasis was on IRCM; for the Navy, a balanced approach between reduced signature and ECM improvements was preferred. This seemed to reflect the varied roles and missions that each service plays in air warfare.

Integrated Survivability: Assessing Survivability Design Trades

- What are the tradeoffs between ECM and signature reduction?
- How should we trade vulnerability and susceptibility design features?
- What metrics have meaning for the warfighter?
- How should we define survivability requirements?

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A “Wizard” for Hydrodynamic Ram Modeling

by Ms. Susan L. Casabella and Mr. J.A. Hangen

The U.S. military has long hardened aircraft against threats. With today's threats, live fire test laws, and highly optimized structures, our military needs effective tools for survivability design that can be used in the early development phase of new aircraft. Design changes are not easily achieved late in the development cycle. The aluminum planes of the past have demonstrated reasonable ballistic resistance; however, composite materials, which are less ductile than metals, have not fared as well in live fire testing. With the increased use of composite materials on next generation aircraft, the challenge to make them survivable is more difficult and requires greater attention. The design and analysis community needs a robust and reliable method of analytically evaluating aircraft survivability.

Design and assessment of aircraft structural survivability often revolves around the phenomenon of hydrodynamic ram, an intense fluid pressure pulse generated by a penetrating projectile. Hydrodynamic ram becomes particularly acute when fuel tanks are full and the projectile is a high explosive incendiary (HEI) threat. Until recently, the prediction of a structure's response to ram has been considered more art than science. As a result of the lack of an acceptable analytical tool, the design community was forced to take an experimental approach of building costly components, performing ballistic tests, redesigning, and retesting. With more advanced software and modeling techniques, we now can effectively simulate ballistic events in aircraft structures, dramatically reducing the amount of destructive testing needed.

Historically, ram analysis has been slow and unreliable, inadequate to meet live-fire laws and specifications demanding survival and residual strength. Recent advances have improved computer hardware, software, and

modeling of ballistic events and dynamic structural response, making them more reliable. These tools, however, are not easy to use. Ram Design Methodology (RamDeM), a JTCG/AS activity led by the 46th Test Wing, considers industry's needs and lessons learned and enables the latest ram-modeling software with a graphical user interface (GUI). This front-end “wizard” will be designed to advise users throughout the ram modeling process and greatly improve the ease and reliability of results. RamDeM will supply unique data for ballistic analysis (see Table 1) that structural designers are not accustomed to using. Because users must otherwise supply their model with so much information (much of which is outside the user's knowledge-base), unsatisfactory results are produced. The RamDeM project seeks to resolve this issue.

Table 1. Variables Addressed Through RamDeM Knowledge Database

ITEM	VARIABLE
Threat Data	Warhead velocity Warhead charge material and mass Warhead total mass Charge detonation properties/ equation of state
Structural Modeling	Finite element analysis (FEA) structural mesh density guidelines
Fluid Modeling	FEA fluid mesh guidelines
Fluid-Structural Coupling	Arbitrary Lagrangian-Eulerian Coupling Guidelines
Structural Material Properties and Allowables	Elastic-plastic stress strain for metals Laminate strain allowables for composites • When to use notched versus unnotched Bolted joint strengths • Pull-through strength for composites Bonded joint strengths • Including effects of through thickness reinforcements in composites such as stitching and Z-pins Strain rate sensitivity

The software tools of choice for ballistic analysis—often called hydrocodes—are finite element-based non-linear transient dynamic analysis codes, which incorporate structures, fluids, fluid-structure coupling, detonation equations of state, and penetration mechanics, and

Table 2. Description of Design Mode and Analysis Mode

DESIGN MODE	ANALYSIS MODE
Survivability rules of thumb	<ul style="list-style-type: none"> Preprocessor for full Hydrocode analysis Patran environment—using Patran Command Language (PCL)
Look-up tables <ul style="list-style-type: none"> Expert system guidelines Preliminary joint loads Recommendations for spar/rib/frame spacing 	Target Analysis Solver—DYTRAN <ul style="list-style-type: none"> Threat data from knowledge-base Structure modeling guidelines Fluid modeling guidelines Automated fluid structure coupling Full transient dynamic analysis with failure progression
Design “do’s and don’ts”	

account for structural failure and failure progression. Two such codes of interest are Dytran and LSDYNA3D. RamDeM software links into these hydrocodes through a Patran interface.

RamDeM software has two modes of operation, a design mode and an analysis mode. A description of each is shown in Table 2.

The RamDeM software operates in conjunction with the user-selected hydrocode and provides advice at each step of the ram modeling process. Users are instructed to simply log onto Patran and click the “RamDeM” button. As shown in Figure 1, the Patran PCL-based GUI then walks each user through a series of questions and

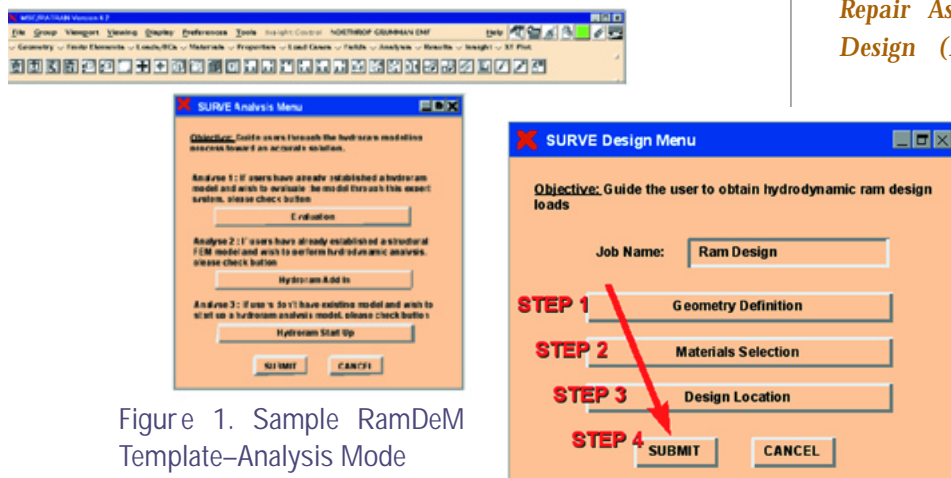


Figure 1. Sample RamDeM Template—Analysis Mode

options. A knowledge base will assist the user by providing answers and selections.

After selecting “Submit,” the ram analysis begins. Stage 1 is analysis through the first millisecond (ms) time frame. Results then transfer to Stage 2 for comple-

tion of the static nonlinear analysis. Stage 3 is used for damage assessment.

The benefits of RamDeM are as follows:

- Reduced design cycle time and expense
- Improved accuracy of simulation leading to increased confidence in achieving a survivable design
- Reduction of design development tests including subcomponent live fire tests
- Improved survivability of military aircraft
- Enhanced consistency and traceability of the analysis and design.

The RamDeM program began in August 1998 and runs through October 2002. Demonstrations and user workshops will be conducted. The software has expandable modules to work with new target codes and to incorporate new lessons learned into the knowledge base and expert system. ■

About the Authors

Ms. Casabella received her B.S. in Mechanical Engineering from Rensselaer Polytechnic Institute. She is an engineering specialist and the Northrop Grumman Corporation (NGC) RamDeM Program Manager. Ms. Casabella has a background in aircraft structural design and computer hardware/software. She is currently the Program Manager of the FAA/Air Force sponsored Repair Assessment Procedure and Integrated Design (RAPID) program and for NGC's Structures Center of Excellence (CoE) initiative to modernize structural analysis methods within NGC. She may be reached at casabsu@mail.northgrum.com.

Mr. Hagen received his B.S. in Mechanical Engineering from Lafayette College and M.S. in Mechanical Engineering from M.I.T. He specializes in the full range of analysis, testing and certification of aircraft structures with background in R&D and production, covering metallic and composite materials. He can be reached at hangeja@mail.northgrum.com.

Decoupled Fuel Cells Program— A Story of Success

by Mr. James J. “Jamie” Childress

The Decoupled Fuel Cells (DFC) program began as a small research study contract in 1995. The goal was simple: investigate concepts for a lightweight, low cost, fighter wing that could survive a 30-millimeter (mm) High Explosive Incendiary (HEI) hydrodynamic ram event. That small contract ultimately resulted in a series of three DFC programs funded jointly by the Air Force and the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS). The DFC's technical direction came from Bill Baron and John Riechers of the Air Force Research Laboratory (AFRL).

DFC developed and demonstrated an innovative wing design that exceeded all the weight, cost, and survivability goals of the program. DFC met its goals on time and under budget in each phase of the program. The total DFC program cost for all phases was only slightly more than \$1 million, yet the program designed, developed, and produced more prototype composite hardware than programs exceeding \$50 million. Therefore, what did the DFC program do, what was the payoff, and why was it successful?

Our Accomplishments

Preliminary Development

We brainstormed 48 hydrodynamic ram tolerant wing designs and refined those designs into two high payoff concepts.

- The first concept was a composite cellular wing design. (The cellular wing design is an all-composite co-cured wing design composed of co-cured tubes with a co-cured skin on the upper and lower skin surfaces.)
- The second concept was a composite tubular truss spar design.

We performed detail design and sized both high payoff concepts to meet modern twin engine fighter aircraft loads.

Preliminary Concept Testing

First, we built and statically tested joint concepts for both high payoff designs. Following that, we built and ballistically tested small hydrodynamic ram test articles for both high payoff concepts (30-mm HEI, full fuel hydrodynamic ram). Based on test results, we down selected to the cellular wing concept as the lightest weight and lowest cost design.

Cellular Wing Refinement and Validation

Over 100 joint tests were performed as the cellular wing z-pinning techniques and joint designs were

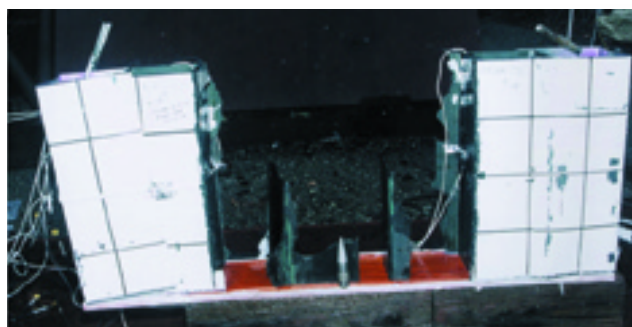


Figure 1. Small-Scale Cellular Wing Ballistic Test Article

refined. We built and ballistically tested a small hydrodynamic ram test article for the refined cellular wing design (Figure 1) (30-mm HEI, full fuel hydrodynamic ram). In addition, we developed appropriate fuel system and systems installation concepts. In preparation for large scale testing, we developed tooling and rib insertion concepts for a large cellular wing ballistic test article. The large scale test article had eight light spars and an intermediate rib line and was the largest z-pinned structure ever constructed. Ballistic tests (30-mm HEI) were conducted with full fuel for hydrodynamic ram (Figure 2).

Complex Manufacturing and Damage Detection System

Significant effort was expended on the DFC program to ensure that we were developing technology that was capable of transitioning to a real aircraft. Complex

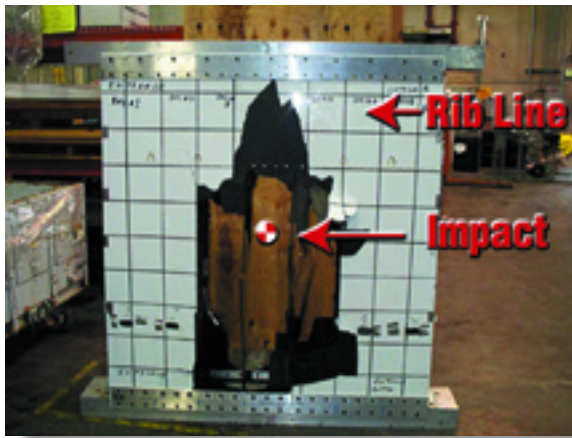


Figure 2. Large-Scale Hydrodynamic Ram Test Box After 30-mm HEI Impact

tapered wing geometry and fuel systems installation were two of the most critical issues that needed to be shown before cellular wing technology would be ready for consideration by future aircraft programs. To prove that cellular wings were a viable production concept we developed the tooling for a highly tapered all composite cellular wing with a 45-degree wing sweep (Figure 3). Next, we developed a method to install ultrasonic fuel gauges into the co-cured section of the wing box (Figure 4). Finally, we showed that these new ultrasonic fuel gauges provided an additional survivability benefit by proving that we could detect damage by monitoring their output during hydrodynamic ram events. Ballistic damage detection tests were conducted that showed the ultrasonic fuel gauges could detect and estimate the location of the ballistic impact with an accuracy of under two inches. This information could be given to the pilot in real time to help him assess the damage state of his aircraft.

What was the Payoff?

The cellular wing design demonstrated an ability to exceed the live-fire test requirements of modern fighter aircraft for hydrodynamic ram tolerance. This design can meet twin engine fighter flight loads, yet is 15 percent lighter than state-of-the-art production designs.

This wing design has fasteners only in access cover areas and selected rib locations, resulting in a 98-percent fastener count reduction for some design cases. And from a cost perspective, the cellular wing design is about 40-percent less expensive than an equivalent bolted design.

In addition to the new fuel cell design, a new low cost, lightweight, highly reliable, ultrasonic fuel gauge

was investigated and tested. The fuel gauge demonstrated that it was capable of being co-cured into the structure and detecting ballistic wing damage in real time. This potential dual use capability of the fuel gauge has possible applications to improve situational awareness and vehicle survivability.

The Decoupled Fuel Cell program resulted in a lightweight, low cost, and highly survivable technology solution that will be available for next-generation flight vehicles. In fact, this technology is already paying off with current new aircraft programs and other research contracts.

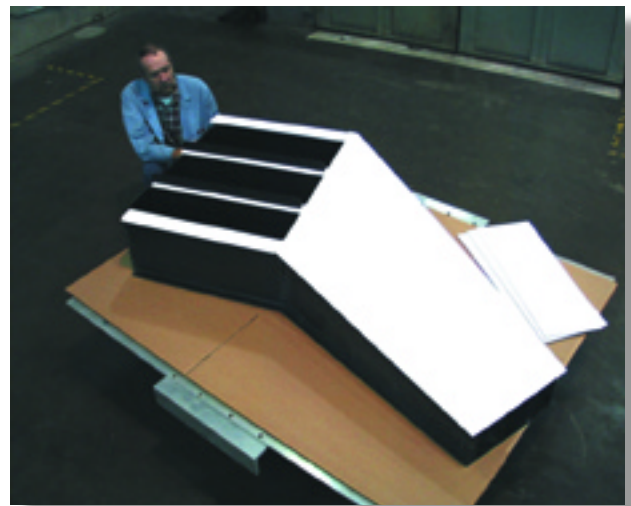


Figure 3. Cellular wing with 45 degree wing sweep and high taper

Why was the Program a Success?

The goals of low weight, low cost, and improved survivability were ambitious, but we were given wide latitude in the design process to meet those goals. Also, we remained focused on developing concepts that could actually fly in a production aircraft—not just be laboratory curiosities. We stayed aware of manufacturing considerations to ensure that the concepts developed could be produced efficiently. We also remained aware of real aircraft requirements to ensure needed aircraft systems could be installed and flight load requirements could be met.

From the administrative side, we held very few formal meetings, but numerous small,

see Fuel Cells on page 29

Reducing Next-Generation Engine Vulnerabilities

by Mr. Charles E. Frankenberger



A new generation of turbine engine will be powering the next generation of fighter aircraft. These engines utilize the latest in control technology, including Full Authority Digital Engine Controls (FADEC) and adaptive control logic, and will provide significant advances in health monitoring. Through these advances in the FADEC, advanced control algorithms provide an opportunity to reduce the engine's vulnerability without adding weight or reducing engine performance. Implementation of these techniques was unavailable previously as a result of limitations in the pure mechanical control system of the past.

A vulnerability assessment was conducted on a single engine aircraft to better understand engine component contributions to the aircraft's vulnerability. The study used a modern airframe with an advanced engine. Results of the study indicated the following:

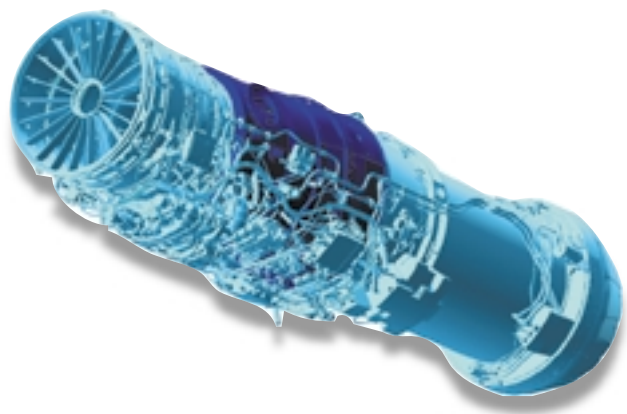
- The engine was a large fraction of the aircraft's vulnerability
- Loss of engine operation results in aircraft loss
- Engine lube and fuel systems were the larger contributors.

These findings provided support to two JTCG/AS efforts (Single Engine Improvement and Engine Control Vulnerability) aimed at addressing the issues of loss of thrust and fuel system damage. Loss of thrust, whether caused by ballistic damage or peacetime circumstances, results in the loss of the aircraft.

Engine Controls

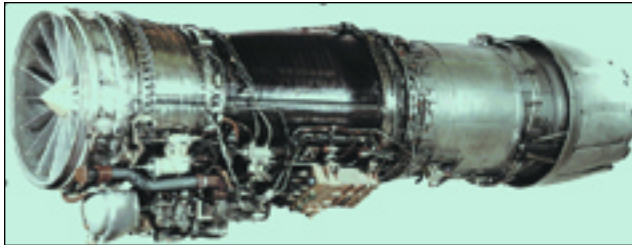
Next-generation engine controls will take full advantage of the computer age, no longer a digital replacement of past generation mechanical controls. These controls provide increased performance, improved stability, and health monitoring. The controls also compensate for component performance deterioration to provide level thrust over the life of the engine.

Engines are subject to ingestion damage during peacetime and ballistic damage in combat. Taking advantage of these advances, engine controls can be used to increase the engine's survival after damage. Adaptive controls monitor the engine performance and adjust the engine controls to improve performance. Extending this theory, survivability enhanced controls will be capable of detecting and mitigating the effect of damage. Engine damage is detected by monitoring changes (shifts) in performance trends. By adjusting the control schedule real-time, the control can mitigate the effect of the damage. The objective of this detection and mitigation strategy is first to keep the engine operating, in a degraded performance mode if necessary, and second to regain as much of the performance as possible to increase the pilot's chances of returning home.



Survivable Controls

- Utilize adaptive engine control theories that:
 - Allow real-time adjustments to engine control schedules
 - Optimize engine performance (thrust or SFC)
 - Compensate for deteriorating engine
 - Are tolerant to loss of sensors
- Detect damage to the gas path
- Mitigate the effect of damage to controls (loss of variable geometry actuators and loss of nozzle control).



General Electric F414-GE-400, F/A-18 E/F Propulsion

Engine Fuel System Vulnerability

Engine fuel system contributions to the aircraft's vulnerability include component dysfunction, fuel leakage, and fire. Eliminating fuel system leakage will reduce the chance of fire in the engine bay and eliminate fuel starvation as a potential kill mechanism. Therefore, providing leak detection and shutoff to the engine fuel system will prevent several hazardous conditions to the aircraft.

Techniques to eliminate fuel and oil system leakage include excess flow valves (EFV), smart valves, and self-sealing lines. EFVs are passive devices that are similar to hydraulic fuses in concept. They detect flows above nominal flow conditions and are pre-sized to provide protection against large leakage flows. To provide active control of leakage flow shutoff, smart valves are used. Smart valves use control logic to determine whether a leakage condition exists and closes a solenoid to shut off the flow. Several techniques have been used to determine whether a leak condition exists: flow or pressure devices, feedback from actuators, or combinations of the above.

Older engines were quite vulnerable to minor damage to the control system. Damage to the hydraulic system powering variable geometry components (specifically, the perforation of fuel transfer tubes

between pumps and actuators) often leads to the loss of control of the engine, resulting in unstable engine operation and engine shut-down. New pump capabilities and advanced controls make the engine more tolerant of this type of damage. State-of-the-art fuel pumps provide large volumes of fluid (fuel) to the actuation systems to keep the control system operable. Damage to this system (fuel transfer lines) results in large quantities of fuel leaking into the engine bay introducing other vulnerability concerns, such as fire and fuel starvation.

The JTCG/AS has been exploring methods to reduce engine vulnerability, using leak detection and shutoff devices, and advanced controls to detect and mitigate the effect of engine damage. Bench testing was conducted on several EFVs to evaluate their operating characteristics. Limited engine testing was conducted on an F414-GE-400 engine to evaluate the valve characteristics during typical engine operation.

The Engine Control Vulnerability project is expanding the capability of the current adaptive engine control logic. Damage detection and mitigation will reduce future engine vulnerability to ballistic threats and improve aircraft safety by increasing the engine's tolerance to bird and ice ingestion events. General Electric is now under contract to the Naval Air Warfare Center Weapons Division, China Lake, to develop detection and mitigation strategies and implement them using an advanced F414 control system. Verification of this capability is planned in FY00. ■

About the Author

Mr. Frankenberger has worked in the propulsion field at NAWCWPNS for 12 years, including 8 years in missile propulsion on programs including Tomahawk, Harpoon/SLAM and Advance Air-to-Air Missile. He has worked Engine Vulnerability issues for the past 4 years conducting ballistic tests on turbine engines under JTCG/AS, JLF and LFT efforts. He may be reached at 760.939.8411.

CF₃I

Trifluoromethyl iodide Trifluoromethyl iodide Trifluoromethyl iodide

A Summary to Date

by Mr. James E. Tucker

Whenever CF₃I (Trifluoromethyl iodide, Triiodide®, halon 13001) is mentioned as a halon replacement, the response is usually polarized to one of two camps: CF₃I is a drop-in replacement for halon 1301 (CF₃Br), or it is the fire-extinguishing equivalent of sarin gas. Each side at some time has made erroneous statements based on inaccurate or outdated information. This article is not intended to advocate either position; rather, it illuminates the subject with the facts known to date. There is no attempt to sway a single manager to make a decision one way or another—only to ensure that when a single manager or policy-maker makes a decision about CF₃I usage, it is an informed decision.

CF₃I was “rediscovered” about a decade ago. The chemical, which has been synthesized in small quantities for decades, was one of the chemicals originally examined in a late 1940’s Purdue University study that focused on brominated halons as fire extinguishers. The Montreal Protocol, which later led to the 1 January 1994 production ban on brominated halons, renewed interest in CF₃I because CF₃I is molecularly analogous to halon 1301 (CF₃Br).

CF₃I compared very well volumetrically with CF₃Br in initial small-scale fire tests. Industry, government, and academic researchers participated in an ad hoc working group to examine other important areas, including materials compatibility, and toxicity, to accelerate the knowledge base building effort. CF₃I was brought into the tri-service/Federal Aviation Administration (FAA) Halon Replacement Program for Aircraft Engine Nacelles and Dry Bays. It underwent a battery of small-scale tests at the National Institute of Standards and Technology’s (NIST) Building Fire Research Laboratory. It became the leading candidate after Phase II

full-scale testing at Wright-Patterson AFB. In small-through full-scale fire testing, CF₃I demonstrated superior fire extinguishing performance over other candidates being tested.

Despite the excellent fire-extinguishing performance of CF₃I, the chemical transitioned from the Halon Replacement Program for Aircraft Engine Nacelles and Dry Bays was HFC-125. Outstanding issues in toxicity—in particular, cardiac sensitization—along with uncertainties in other areas, resulted in CF₃I being dropped from further consideration. The program was under a stringent time line that forced the decision-makers to reach a conclusion without the benefit of further investigation to resolve the outstanding issues. However, since that decision, additional data has emerged that addresses many of the issues related to CF₃I.

Table 1. Environmental Properties of Common Fire-Extinguishing Agents

	GWP	Atmospheric Lifetime	ODP
CF ₃ I	5	days	0.0002
Halon 1301	5600	50 years	10 to 14
HFC-125	2800	33 years	0

As shown in Table 1, CF₃I is environmentally friendly. CF₃I has a global warming potential (GWP) of five (5) and an atmospheric lifetime of days. CF₃I breaks down in the troposphere as a result of the blue component of sunlight, and little if any reaches the stratosphere. CF₃I does have an Ozone Depleting Potential (ODP) of 0.0002 with the greatest potential damage coming with discharges above 25,000 feet. Historical numbers of halon discharges show this to be an infrequent occurrence. At the time of its initial inclusion in the Significant New Alternatives Policy (SNAP), the low probability of discharge combined with CF₃I’s low ODP, did not represent a concern to the Environmental Protection Agency (EPA).

Other important characteristics for measuring the performance of a fire-extinguishing agent are long-term

storage and materials compatibility. The most well known storage and materials compatibility data were generated by the National Institute of Standard Technology (NIST) (Gann, 1995). The statistically significant changes in stability observed during the 52-week storage tests occurred only at 150 degrees C (302°F). Tests conducted at 23 degrees C (73.4°F) and 100 degrees C (212°F) showed no statistically significant changes. The NIST report further elaborates: “Even though some of the areas at 150°C are showing ‘statistically significant’ differences, the actual loss in agent is probably quite small and poses no problem to the fire extinguishing capability of the CF₃I.”

The material’s compatibility data contained in the same report demonstrated that like HFC-125, HFC-227ea, and halon 1301, CF₃I is compatible with a wide variety of seals and elastomers. In long-term liquid storage tests, problems did appear with titanium. These problems are of concern if titanium bottles are employed for CF₃I storage. The short-term gas phase materials compatibility tests, representing CF₃I discharge during a fire, indicated no concerns and verified that CF₃I was a clean agent with no residue.

CF₃I toxicity fits within the range of fire extinguishing agents and refrigerants commonly used within the Department of Defense (DoD) and the commercial sector (see Table 2). A battery of toxicological tests has been run to ascertain acute and chronic toxicity effects. An important acute toxicity endpoint for CFCs and their replacements is cardiac sensitization, which is the sensitization of the heart to adrenaline and similar

chemicals. CF₃I has a cardiac sensitization No Observable Adverse Effects Exposure Level (NOAEL) of 0.2 percent and a Low Observable Adverse Effects Level (LOAEL) of 0.4%. This is of the same order toxicity as halon 1211, CFC-11, and halon 2402, which are an order of magnitude lower (more toxic) than CF₃Br and HFC-125.

In addition to the acute toxicity endpoints, much information has been learned from genotoxicity test results. Some interpreted the positive results in the Ames bacterial test system (which is an initial screening test) as an automatic flag that CF₃I would pose chronic toxicity problems. However, like the positive results that were seen with halon 1211, during its developmental testing, this indicated only the need to perform higher fidelity genotoxicity tests. Since that initial test series the following additional tests to determine chronic toxicity have been performed: in vitro mammalian cell assay, in vivo micronucleus assay, short-term repeated exposure, 90-day repeated exposure, and developmental and reproductive toxicity. (A 2-year bioassay has not been conducted, and it is unlikely that it ever will be because there are not enough indications to justify the need.) These test data for establishing chronic toxicity were evaluated by the EPA and resulted in their recommendation for an 8-hour Time Weighted Average (TWA) exposure limit of 150 ppm with a ceiling of 2,000 ppm. As shown in Table 2, these numbers are of the same orders as halon 1011 and

1202. These halons are still used on C-130 model aircraft (except the C-130J).

As with any potentially hazardous chemical, all efforts should be made to minimize or prevent personnel exposure. The potential user must take into account the haz-

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Table 2: Toxicity Endpoints for Common Fire Extinguishing Agents and Refrigerants .

Extinguishing Agent	NOAEL (ppm) (Cardiac Sensitization)	LOAEL (ppm) (Cardiac Sensitization)	TWA (ppm)	Ceiling
CF3I	2,000	4,000	150 (rec.)	2000 (rec.)
halon 1301	50,000	75,000	1,000	1,200
halon 1211	5,000	10,000		
halon 2402		1,000		
halon 1011			200	250
halon 1202			100	250
CFC-11	3,200	3,500	1,000	1,000
HFC-125		100,000		

continued from page 17

ards of chemical exposure and the probability of such an exposure. A Boeing examination of two widely deployed USAF fighter/attack aircraft found no reports of accidental agent discharge, whereas a similar review of a USN fighter/attack aircraft showed 50 discharges per 1,000 aircraft per year. The hazard is the same, but the risk is different. It is the overall risk that must be assessed. Only by examining the application and understanding the system can the potential user fully appreciate the risk.



Two F-16C's fly in formation during a mission in support of NATO Operation Allied Force. DoD Photo by: SRA Greg L. Davis.

The only U.S. platform to date that has performed application specific work on CF₃I is the F-16. Fuel tank inerting tests against ballistic threats were conducted at the Aircraft Survivability Research Facility (ASRF) at Wright-Patterson AFB to size the CF₃I system required to achieve halon 1301 equivalence. The F-16 System Program Office sponsored tests showed that a CF₃I system could be designed to fit within the same volume, but with a 30 percent increase in weight. Tests are still ongoing to determine CF₃I solubility in JP-8, long-term gas phase materials compatibility, required system modifications, and approximate implementation costs. An examination of the fuel tank inerting application demonstrated no increase in risk versus halon

1301 (a Mil-Std 882C study has not yet been conducted). This body of information will be incorporated into a contingency plan to be implemented if the current halon 1301 stockpile were to be no longer available.

Much information is available on CF₃I. However, some outstanding science and technology issues still exist, including: low temperature performance (CF₃I has a boiling point of 9 degree F, whereas halon 1301 has a boiling point of 72 degrees F), and additional full-scale experiments to determine sizing criteria for other applications (e.g., aircraft engine nacelles and dry bays).

Each existing or future platform considering CF₃I (or any fire extinguishing agent for that matter) must weigh the pros and cons for its application. It is only in the context of usage that the risks can be understood completely and an accurate, informed decision made. ■

About the Author

Mr. Tucker received his B.S. in Mechanical Engineering and his M.S. in Fire Protection Engineering from Worcester Polytechnic Institute. He has worked in the arena of halon replacement and aircraft survivability both as an Air Force officer and now as an employee of Applied Research Associates. He has served as co-chair of the JTCCG/AS Vulnerability Reduction Group Fuels committee. Currently he works in support of the Aerospace Survivability Flight, 46 OG/OGM/OL-AC specializing in fire/explosion RDT&E. He may be reached at james.tucker@wpafb.af.mil

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WPAFB Engineer Receives NDIA Combat Survivability Leadership Award



by Mr. John M. Vice

Mr. Ralph W. Lauzze, II, 46th Test Wing Aerospace Survivability Flight, Wright-Patterson Air Force Base (WPAFB), Ohio, received the National Defense Industrial Association's (NDIA) Combat Survivability Leadership Award at the Aircraft Survivability 1999 Symposium held recently at the Naval Postgraduate School, Monterey, California. The award is presented annually at the NDIA Combat Survivability Division's Aircraft Survivability symposium, and it recognized Mr. Lauzze's superior performance over many years in positions of leadership in the aircraft survivability community. Through his efforts, significant achievements were made in developing vulnerability reduction technologies, in live fire testing, and in joint service cooperation. The Aerospace Survivability Flight, an operating location of the 46th Test Wing, Eglin Air Force Base, Florida, was recently activated at Wright-Patterson Air Force Base by transferring aircraft survivability expertise from the Air Force Research Laboratory Air Vehicle Directorate.

Mr. Lauzze's contributions to the enhancement of aircraft survivability were manifest throughout his tenure as Test Team Leader, Group Chief, and Branch Chief at the Air Force Research Laboratory. With his guidance, the laboratory developed new applications for fire and explosion suppression foam, Halon fire suppression systems, alternative agents to Halon, nitrogen inerting systems for fuel tanks, and survivable advanced composite structures for aircraft. In addition, he aggressively led efforts to improve the realism of aircraft vulnerability testing through upgrades to the Air Force Aircraft Survivability Research Facility.

In furthering joint service cooperation, he performed with distinction as Test Director for the Joint Live Fire (JLF) program and as Chairman of the Principal Members Steering Group of the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS). The JLF program, which is credited as being the original project validating the benefits of live fire testing, continues to push the state of the art in realistic vulnerability and lethality testing. Additionally, the



Ralph Lauzze (center) shown receiving the NDIA Combat Survivability Leadership award with Awards Committee Chairman, Jerry Wallick (left) and NDIA Combat Survivability Division Chairman RADM Bob Gormley, USN (Ret.).

JTCG/AS remains the recognized authority on aircraft survivability in the Department of Defense, as affirmed recently by a request from the Office of the Secretary of Defense for the group to identify survivability enhancements for aircraft subject to attack by man-portable air defense systems.

Mr. Lauzze has demonstrated noteworthy leadership in the aircraft survivability field, and he clearly exemplifies the level of superior performance that the Leadership Award represents. ■

About the Author

Mr. Vice is President of Skyward, Ltd., a small business located in Dayton, OH, providing professional services to the DoD and DoD contractors in Modeling & Simulation, Weapon Systems Analysis, Test Planning and related areas. Mr. Vice may be reached at 937.427.4261 or by E-mail at jvice@skywardltd.com.

Spacecraft

Survivability's Next Frontier

by Dr. Joel D. Williamsen and Dr. Jeffery R. Calcaterra

"The U.S. will spend more than \$250 billion in space by the year 2000, and another 1,800 satellites will be on orbit by the end of the next decade. This skyrocketing investment must be protected—from natural and man-made threats, accidental and intentional threats."

General Howell Estes
Commander, U.S. Space Command
"Protecting U.S. Assets in Space," *ISIR*, June 8, 1998

The importance of satellites to our military and economic infrastructure cannot be overemphasized. One of the U.S. Air Force's core competencies is information superiority—and this future is predicated on the development of space, the "high ground" for command, control, and communications, observation, weapon guidance and other important military functions. It is estimated that space systems were the primary means for more than 85 percent of intratheater and intertheater communications during Desert Shield and Desert Storm.

Contrary to popular opinion, military dependence on space does not only include military. A recent study by the National Defense Industrial Association (NDIA) predicted that the U. S. Air Force would depend on commercial space systems for more than 30 percent of its remote sensing and 60 percent of its communications requirements by the year 2010—with an even larger percentage of dependence (60 percent and 90 percent, respectively) during times of war. Consequently, the removal of a satellite could cause severe damage to our military's infrastructure. This was best exemplified by the loss of the Galaxy IV satellite on 19 May 1998, which stopped pager service to 90 percent of the 45 million pager users nationwide. If such a satellite were lost during wartime,

the interruption of satellite information flowing to the Armed Forces could have catastrophic consequences.

From the beginning of the space age, satellite designers have been faced with a variety of hazards to satellite survival from the natural space environment. These early hazards could be thought of as either electromagnetic or kinetic. Electromagnetic hazards include cosmic rays, solar flares, and trapped particles from the Van Allen radiation belts. Kinetic hazards include meteoroids (ice and dust particles impacting spacecraft as Earth's orbit crosses ancient comet tails at tens of kilometers per second) and atomic oxygen (molecules from Earth's extreme upper atmosphere impacting spacecraft surfaces).

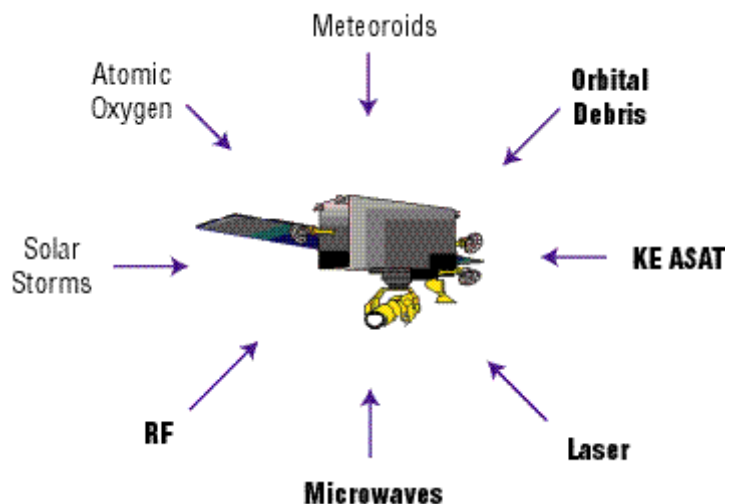


Figure 1. Spacecraft environment includes hazards and man-made threats (in bold face).

In recent years, however, these natural hazards to spacecraft have been joined by additional man-made threats (see Figure 1). Additional electromagnetic threats may include lasers, high-powered microwaves, and radio frequency (RF) jamming. Additional kinetic threats include orbital debris (man-made particles crossing the orbits of satellites) and kinetic energy antisatellite (KE-ASAT) warheads with fragments that impact spacecraft at speeds from 5 to 15 kilometers per second. These threats are similar to air combat threats in that they are often highly directional (usually

approaching from the front, sides, or bottom of the spacecraft), inflict predictable levels of damage to the target, and affect different spacecraft subsystems with varying levels of success.

In their construction, satellites have many design features in common with military aircraft. Both systems are designed to maximize performance while minimizing weight. Both have intricate and redundant guidance, power, communications, cooling, and propulsion subsystems that are distributed throughout the airframe. Both are able to maneuver out-of-the-way of threats. However, differences also exist. Spacecraft operate at longer ranges from directed threats than aircraft, are less maneuverable, and are much more predictable in their movements over enemy territory.

Despite these differences, however, it is clear that the classic tenets of aircraft survivability methodology—reduction in susceptibility (probability of hit) and vulnerability (probability of loss given a hit)—have a direct application to spacecraft. Some air combat vulnerability reduction methods and tools have already been applied to selected spacecraft. The National Aeronautics and Space Administration's (NASA) BUMPER and MSCSurv computer codes utilize limited aspects of vulnerability modeling methods to determine the probability of spacecraft penetration by meteoroids and orbital debris (see Figure 2). Years ago, the Air Force Research Laboratory (AFRL) modified the Fastgen/Covart computer code to model laser damage effects on spacecraft (now referred to as the Satellite Vulnerability Assessment code). Finally, NASA managers are busily testing on-orbit repair techniques for the International Space Station. These techniques are based largely on advanced aircraft battle damage repair techniques (see Figure 3).

However, additional improvements to spacecraft survivability are possible through the extension of better vulnerability assessment tools (such as Advanced Joint Effectiveness Model [AJEM]) to the spacecraft regime. Currently, satellite designs are predicated on durability, which means that there is redundant circuitry to perform critical functions, but these redundant circuits may all be located in the same area, enclosure, or wire bundle. Designers might achieve a significant increase in satellite survivability by simply separating critical redundant components into different areas.

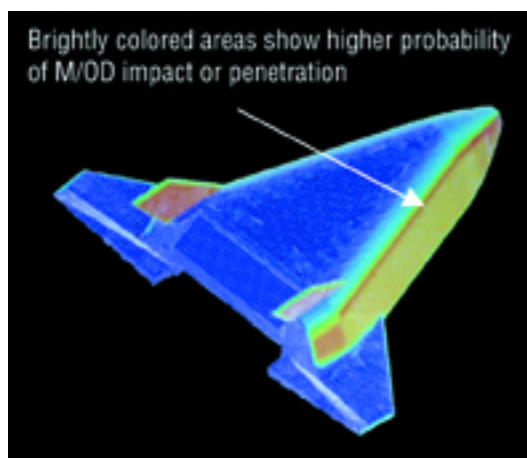


Figure 2. NASA's BUMPER computer code models the probability of orbital debris penetration on a proposed reusable launch vehicle.



Figure 3. NASA workers perform a "zero gravity" KC-135 test of an external repair patch prototype for the International Space Station.

Moves have been made to bring air and space vulnerability communities closer together. Members of the Joint Technical Coordinating Group on Aircraft Survivability (JTCG/AS) and American Institute of Aeronautics (AIAA) and Astronautics Survivability Technical Committee (ASTC) have approached not only the Air Force's Space Command, Research Laboratory, and 46th Test Wing, but also NASA and other diverse government agencies to explore how aircraft combat survivability enhancement methods and tools may be applied to enhance spacecraft survivability. These organizations have joined with the University of

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Space & Air Survivability Workshop

12–14 June 2000

U.S. Air Force Academy
Colorado Springs, CO

US SECRET/NORFORN

Contact: Dr. Joel Williamsen
303.871.4502
jowillia@du.edu

Sponsored by:



Denver to participate in the Space and Air Survivability Workshop 2000 (jointly sponsored by the AIAA and the Department of Defense [DoD] JTCG/AS) for June of next year. The purpose of the workshop is to (1) summarize space environment hazards and directed threats to commercial and military spacecraft performance, (2) discuss spacecraft survivability analysis methods, tools, and test techniques, and (3) explore how aircraft survivability methodologies and enhancement techniques might be applied to improve spacecraft survivability. The workshop will be held on 12 through 14 June 2000 at the U.S. Air Force Academy in Colorado Springs, Colorado. For more information, please check out the workshop Web site at www.du.edu/dri/space_survivability.html. See you there! ■

About the Authors

Dr. Joel Williamsen is currently serving as the Director of Space Systems Survivability at the University of Denver Research Institute, where his responsibilities include space vehicle survivability and lethality analyses, system simulations, hypervelocity impact testing, and damage modeling in support of NASA, Air Force, and commercial spacecraft clients. Prior to joining DRI, he was lead engineer for the design, analysis, and repair of space station meteoroid and orbital debris protective structures at NASA-Marshall Space Flight Center. Dr. Williamsen is currently serving as the secretary of AIAA Working Group for Survivability Technical Committee, and as the chairman of the AIAA Working Group for Spacecraft Survivability. He will serve as the Chairman of the Space and Air Survivability Workshop in June 2000 and may be reached at jowillia@du.edu.

Dr. Jeff Calcaterra is the lead spacecraft survivability engineer for the 46th Test Wing's Aerospace Survivability Flight. His responsibilities include spacecraft vulnerability analysis, warhead lethality studies and system level damage characterization. Dr. Calcaterra has extensive experience in the damage mechanics, fatigue behavior and reliability analysis of advanced materials and structures. He has authored over 20 conference and journal publications in these areas. He is the Technical Chairman for the Space and Air Survivability Workshop in June 2000. He may be reached at Jeffrey.Calcaterra@wpafb.af.mil.

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During this session, numerous techniques were discussed that addressed reduced radar cross-section (RCS) for IR suppression and countermeasures systems. Survivability metrics that were meaningful to the warfighter were developed to support the F/A-18E/F operational readiness review, such as situational awareness, threat performance (e.g., detection range and number of exposures), aircraft vulnerability, and threat engagement survivability. It was apparent from the session that a balanced approach to survivability (among signatures, countermeasures, IR, RF, and vulnerability) is crucial to air vehicle design. An integrated survivability assessment process is required to adequately evaluate survivability design tradeoffs. Ultimately, however, affordability will be the final arbiter of the success of any air-vehicle system-acquisition program.

Future Platforms: Meeting the Challenge

A variety of issues surrounding emerging threat initiatives were raised during previous symposium sessions. This last session looked into how those previous issues were being addressed by current and future aerospace programs:

- How are current and advanced air vehicle programs addressing these challenges?
- Are innovative techniques being proposed or implemented?
- Do special issues exist regarding maintenance, training, safety, battle damage repair, and affordability?
- Are operational lessons from recent conflicts affecting future acquisitions?

Current and advanced air vehicle programs are addressing the challenges posed by the evolving threat through well-balanced designs for survivability. Perhaps ironically, affordability as a driving factor in system development has forced newer acquisition programs to eschew a single-point survivability solution as too costly. Balancing some signature reduction with improved countermeasures, situational awareness tools, and a measure of vulnerability reduction appears to provide a viable, minimal cost solution. Innovative techniques such as uninhabited combat aerial vehicles (UCAV) are being pursued to support manned air systems. Integration of assets, including support assets, in mission planning and maintaining information superiority

are essential to success in the battlespace of the future.

The application of conventional air vehicle survivability approaches to spacecraft is in the offing, but it remains to be seen how much of air vehicle survivability technology and methodology actually will be applied to space. There will certainly be a place in the future for aircraft vulnerability assessment methodologies and ballistic vulnerability reduction technologies to support spacecraft design. To explore that interaction, the JTCG/AS and AIAA are sponsoring a workshop addressing Space and Air Survivability, from 12–14 June 2000 at the U.S. Air Force Academy in Colorado Springs, Colorado.

Recent conflicts have highlighted the lethality of the MANPADS threat. Innovative techniques for improving situational awareness, susceptibility reduction, and especially vulnerability reduction will be required to counteract this widely proliferated class of threats.

Poster Session

Mr. Ron Dexter (SURVICE Engineering) organized an excellent poster session. Twenty-two poster papers were presented on various subjects, ranging from Tri-Service MANPADS vulnerability activities to recent changes in Russian (Commonwealth of Independent States) Integrated Air Defense Systems. The award for best poster paper was presented to the Tri-Service MANPADS entry, authored by Mr. Leo Budd (NAWCWD), Mr. Alex Kurtz (46th Test Wing), and Mr. Mark Mahaffey (USARL). ■

About the Author

Mr. Hall is Chief Analyst of the NAWCWPNS Survivability Division; Co-Director of the Joint Accreditation Support Activity (JASA); Chairman of the Methodology Subgroup of JTCG/AS; JSF Survivability IPT Analysis & Modeling Lead; and Chairman of the NAWCWPNS Analysis Resources Science and Technology Network. He may be reached at 760.927.1297.

The Modeling & Simulation Information Analysis Center

by Mr. Phil L. Abold

In early 1999, the Defense Technical Information Center and the Defense Modeling and Simulation Office (DMSO) combined the Modeling and Simulation Operational Support Activity and the Defense Modeling and Simulation Tactical Information Center to build a complete, technically advanced, and expansive information center—the Modeling and Simulation Information Analysis Center (MSIAC).



With the drawdown in the Department of Defense (DoD) and the impact of far-reaching budget cuts in all areas of the defense industry, we find ourselves at a crucial juncture within the world of modeling and simulations (M&S). The MSIAC is a tangible and intangible place—it is a Web site, a help desk, or a telephone conversation with a subject matter expert (SME). It is research on emerging conflicts; and it is right now, yesterday, and

tomorrow. Our goals are your goals—to take M&S problems off your plate, help you explore emerging technologies, assist with reuse and interoperability, and support M&S throughout the community.

Our mission at the MSIAC focuses on—

- Being a center of excellence for M&S knowledge and operational support
- Increasing productivity through promoting reuse and interoperability
- Supporting M&S across all lifecycle phases
- Facilitating interface of real-world systems with M&S technology
- Providing operational support to increase operational effectiveness
- Offering a contracting vehicle for technical area tasks (TAT).

The M&S community reaches across hundreds of domains, each focused on specific areas within M&S: from the defense program manager debating next year's budget and how it will affect his plans for training troops, to the contractor searching for the most cost-effective solution to building computer interfaces. Whatever the question or challenge—the MSIAC holds the resources, key players, and know-how to tackle every situation.

Listed below are some of the projects we're working on as part of the MSIAC support provided to the community.

Joint Experimentation Force Experiment (JEFX)-99

JEFX-99 was, by design, the U.S. Air Force's most ambitious large-scale experiment in scope, complexity, and sheer numbers of system and process initiatives. As such, JEFX-99 consisted of a myriad of dependent and independent variables requiring coordination across experiment design, control, and assessment functions to test the experiment hypothesis. In concert with the 1995 Four Star Summit's New Vector and the C2 Task Force visions for M&S, the AFC2ISRC requested for the first time, that the MSIAC conduct an assessment of the M&S architecture supporting JEFX-99. The MSIAC

Assessment Team recommended that the JEFX-99 M&S architecture be baselined and placed under configuration management, that a transition plan be developed, that the Air Force take advantage of future collaboration opportunities with U.S. Joint Forces Command (USJFC) and the other Services, and that the Air Force implement “Enterprise Model Initiative,” and establish an Enterprise “Operational Architecture.”

Modeling and Simulation Resource Repository (MSRR)

The MSRR is a program designed to facilitate sharing of resources among M&S community members. DMSO sponsors a repository node, located at the MSIAC, that provides repository services for resources sponsored by the joint M&S community, and for those resources considered to be DoD enterprise level resources.

The MSIAC MSRR node is affiliated with other systems throughout DoD. These systems provide users with access to a broad spectrum of information on M&S. The following organizations operate MSRR nodes, making the MSRR a “system of systems:”

- Army
- Navy
- Air Force
- Ballistic Missile Defense Organization
- Defense Intelligence Agency
- Assistant Secretary of Defense (ASD) C3I's C4ISR Decision Support Center
- Master Environmental Library (MEL).

Impact Assessment

Recently, the DoD and M&S Industries called for finding the value of M&S as it relates to manufacturing, training, and budgeting throughout the community. This is where impact assessment figures into the M&S game plan. The MSIAC Web site hosts the only DoD-sponsored special interest area (SIA) for impact assessment that includes areas for threaded discussions, news updates, and breaking information about measuring and gauging the impact of M&S.

MSIAC Services

Our robust help desk is staffed with highly experienced personnel who will either solve your problem themselves or find someone who can by capitalizing on our extensive cadre of SMEs. The help desk is a central



meeting point for other people across the M&S community who are working on similar issues and facing identical challenges—people who can not only provide you with added insight and opportunities to share capabilities, but also promote reuse and interoperability.

Our M&S technical support staff, along with the help desk, can provide planning, execution, and assessment support, or at least get you moving in the right direction. This staff has extensive experience in planning, conducting, and assessing M&S events, such as exercises, experimentation events, workshops, and conferences.

The MSIAC is an unbiased source of M&S news and community support, including our all-inclusive M&S calendar that lists DoD and non-DoD related events, and the MSIAC's M&S Journal Online, a quarterly journal replete with M&S technology updates, current

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Pioneers of Survivability

Dale B. Atkinson

by Distinguished Professor Robert E. Ball

According to the American Heritage Dictionary, a pioneer is an innovator or one who participates in the development of a new field. The gentleman we are honoring in this issue, Dale B. Atkinson, is truly a pioneer in survivability in both meanings of the word.

Dale graduated from high school in Kansas in 1953 and became a co-op student at White Sands Proving Grounds while enrolled at New Mexico State University. He then joined the Air Force and became an aircraft mechanic with the 306th Bomb Wing, Strategic Air Command (SAC), at MacDill Air Force Base (AFB) in Tampa, Florida. In 1955, he married Carroll Jones, and a year later, their son Douglas was born. In 1961, Dale graduated from the University of Kansas with a B.S. in Aeronautical Engineering.

After graduation, he worked at the Air Force Flight Dynamics Laboratory (AFFDL) at Wright-Patterson AFB in Dayton, Ohio. His first assignment was with an in-house scientific team conducting research on electromagnetic influences on hot gases in propulsion systems, where he designed and supervised the construction of a small wind tunnel and a hot gas tunnel. This hands-on laboratory experience helped prepare him for his future contributions to research in survivability.

Dale then moved to the Structures Division, where he managed a project to develop techniques to protect spacecraft from meteoroid impact. During this time, U.S. aircraft losses in the war in Southeast Asia (SEA) began to mount. Because Dale understood impact physics, he was asked to help determine why these aircraft were being shot down. This was his introduction to survivability, and he began reading all of the literature he could

find (there wasn't much) and planning some laboratory activities.

In 1966, Dale led an AFFDL team that conducted an in-field study of U.S. Air Force (USAF) combat aircraft losses in SEA. He briefed the results of the study to the USAF/AFSC R&D Council, and all the team's recommendations were endorsed as action items by the Council. As a result, AFSC Project 5105 was initiated to conduct vulnerability analyses of several aircraft. The project resulted in survivability modifications being made to the F-105 and F-4 and eventually to other aircraft.

After his success in determining the causes of many of the USAF losses in Southeast Asia, Dale was appointed Chief of what eventually became the AFFDL's Survivability Branch. He started with just himself and a secretary, and when he left several years later the Branch had grown to almost 40 people. He established the Air Force Survivability R&D Program and developed what was later called the Air Force Aircraft Survivability Research Facility. This facility included the first vertical firing range with airflow. It was used for realistic, in-house testing and research to help understand the very complex phenomena that occur when an aircraft is hit by a warhead and to develop techniques and technologies for reducing aircraft vulnerability. Dale and his people were also involved in supporting numerous aircraft survivability programs, and he played a major role in establishing survivability programs for the A-10 and F-15 aircraft.

In 1967, Dale led a team that performed a second in-field study in SEA and again presented the results to the USAF/AFSC R&D Council. He received the Council's approval for additional survivability programs. The data collection techniques developed by the AFFDL in-field teams were used by the Air Force Battle Damage Assessment and Reporting Team (BDART), which was formed as part of the tri-Service Battle Damage Assessment and Reporting Program established by the Joint Technical Coordinating Group for Munitions Effectiveness (JTCG/ME). The establishment



Dale Atkinson with his wife, Caroll, and RADM Bob Gormley, USN (Ret.), after receiving the NDIA Combat Survivability Lifetime Achievement Award presented at the NDIA 1999 Aircraft Survivability Symposium.

of a long-term data collection effort had been one of the recommendations of Dale's team. Another recommendation was to establish a permanent repository for this type of information. This recommendation resulted in the creation of the Combat Data Information Center (CDIC).

In 1968, Dale was instrumental in establishing the AFSC Non-nuclear Survivability Technology Working Group (NSTWG), which included all the Air Force laboratories and other Air Force organizations involved in conducting survivability R&D. The group was to improve coordination and communication among the various Air Force organizations involved in survivability, to prevent duplication, and to make scarce resources go further by joint planning. This group was composed of several subgroups that addressed all areas of survivability, including the Observables Subgroup. Dale conceived the organizational structure of this group, which significantly improved the coordination and communication among the laboratories.

Dale was also actively involved in several ad hoc inter-Service committees devoted to coordination of survivability activities across the three Services. He was a strong advocate for a permanent organization that

could accomplish this coordination in a more authoritative manner. Dr. Joe Sperazza, Chairman of the JTCG/ME, formed a Survivability Committee under the JTCG/ME. This Committee provided the survivability advocates a forum to lobby for a permanent group for the survivability area. Eventually, the JTCG/AS was established in 1971. Dale was a member of the committee that wrote the charter.

By 1972, Dale had been living in Dayton's sinus valley for 11 years, and he began to have year around sinus infections that doctors couldn't cure. Furthermore, he had always wanted to own his own business. So he and his family, which now included daughters Lisa and Laura, moved to Belen in the New Mexico desert, to help his sinus problem, and started a Western Auto Store. Six months later, after deciding that owning a Western Auto Store was not really his life's calling, Hugh Drake (another pioneer) arranged for Dale to get a job at the Naval Weapons Center (NWC), China Lake, CA, heading up the Survivability Technology and Test area. A year later, this area was designated as a Branch, and Dale was named Branch Head. Hugh and Dale then lobbied to merge Dale's Branch with Hugh's Warhead Analysis Branch into the Survivability and Lethality Division. This Division included survivability technology, analysis, and test functions, and Dale became the Associate Division Head. By 1975, Dale's sinus problems seemed to be under control, and Caroll wanted to move back to the East where all her family was located, so Dale took a position at the Naval Air Systems Command (NAVAIR) in Washington, DC.

From 1975 to 1990, Dale helped establish and later headed the Combat Survivability Office at NAVAIR. He continued to play a major role in establishing the combat survivability design discipline as part of the acquisition process. Dale and his people supported

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weapon system program offices, such as the F/A-18, V-22, and other systems, and he served as the Advanced Development Project Officer (ADPO) for the Naval Air Combat Survivability R&D Program. He was the original survivability project engineer on the F/A-18, which proved to be a survivable aircraft in Desert Storm.

Dale's last government assignment was in 1990 as the first Staff Specialist for Survivability and Battle Damage Repair for Tactical Systems within the Office of the Under Secretary of Defense for Acquisition. There, he was responsible for overseeing the survivability programs for tactical systems, such as the F-22, and providing a formal evaluation of the survivability of major weapons systems to the Chairman Conventional Systems Committee. Dale retired from government service in 1992 after over 34 years of dedicated service. He has continued to provide leadership through his work with the JTCG/AS, the Institute for Defense Analyses, and other organizations.

During his career, Dale attended a number of schools, including the Program Managers Course at the Defense Systems Management College in 1976; the Industrial College of the Armed Forces in 1979, where he also obtained an M.S. in Administration of National Security Affairs; and the Harvard Senior Officials in National Security Course in 1991.

Dale has been a strong proponent of teamwork for the good of the survivability design discipline and a strong supporter of the JTCG/AS. Over the years, Dale served in numerous roles in the JTCG/AS, including Co-chairman and then Chairman of the Technology R&D Subgroup (now the Vulnerability Reduction Subgroup), Technical Advisor and Director of Assessments and Methodology for the JTCG/AS Central Office, member of the JTCG/AS Planning Advisory Committee, and Navy Principal Member from 1981 to 1990. Dale was Chairman of the JTCG/AS from 1981 to 1988, longer than any

other person in that position. Dale was a source of inspiration and innovation that revitalized the JTCG/AS. These years became known as the "golden years," during which many of the survivability handbooks and military standards were completed; the Navy-JTCG/AS Survivability Short Course at the Naval Postgraduate School was developed by Dale, John Morrow from NWC, and the author; the AIAA Survivability textbook was completed; the Joint Live Fire Test Program was initiated; and the Survivability/Vulnerability Information and Analysis Center (SURVIAC) was established in cooperation with the JTCG/ME.

Dale has received numerous awards over the years, but is particularly proud of receiving the first AIAA Survivability Award in 1994 for "Pioneering efforts in establishing survivability as a recognized design discipline" and the NDIA Survivability Lifetime Achievement Award presented at the 1999 Aircraft Survivability Symposium in Monterey last November. In addition, he received a letter from Secretary of Defense Richard (Dick) Cheney in 1992 recognizing his efforts and stating, "As evidenced by our Desert Storm successes, your efforts helped to provide our aircrew members combat aircraft that could survive battle damage and return to fight another day."

Dale has asked me to express his appreciation to all of the people he has worked with over the years who helped establish survivability as an integrated design discipline and who helped foster coordination, communication, and cooperation across all the Services. Dale said there were too many people who helped to list in this short article, but they know who they are, and he thanks all of them and appreciates their efforts. Dale said that collectively we have all made a difference. Dale singled out his wife Carroll, who has supported him in everything he tried to do for the last 45 years, and his family. Dale said that without such a supportive wife and family, he could not have accomplished everything that he did, and he is forever grateful to them.

The author would like to express for all who have worked with Dale over the years our appreciation for all that he has done for us and for our discipline. He has selflessly advanced the cause of aircraft combat survivability, always sharing his knowledge with others and ensuring that his colleagues received recognition for their accomplishments. Dale is truly a pioneer in survivability. ■

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trends, and objective articles written by and for the M&S community.

In summary, the MSIAC is a one-stop shop for M&S information, technology, support, and management. It is a knowledge source that will help M&S developers, users, managers, and decision-makers conserve funding by locating M&S assets that already exist and putting those assets within reach. Whether you have a simple question about high-level architecture or a complex challenge meeting exercise requirements, call on the MSIAC for help in M&S. ■

About the Author

Mr. Phillip Abold is the Director, Modeling and Simulation Information Analysis Center, IIT Research Institute. He has held this position since 1 June 1999. From August 1993 to May 1999, he was the Vice President for the Modeling and Simulation Group at AB Technologies, Inc. Mr. Abold was awarded a B.S. in Aeronautical Engineering from the U.S. Air Force Academy in 1967 and an M.S. in Aeronautical Engineering from the Air Force Institute of Technology in 1968. He undertook Postgraduate Studies in Artificial Intelligence at the University of Dayton.



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Fuel Cells

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short, and informal ones. We solicited advice from shop technicians because, since they

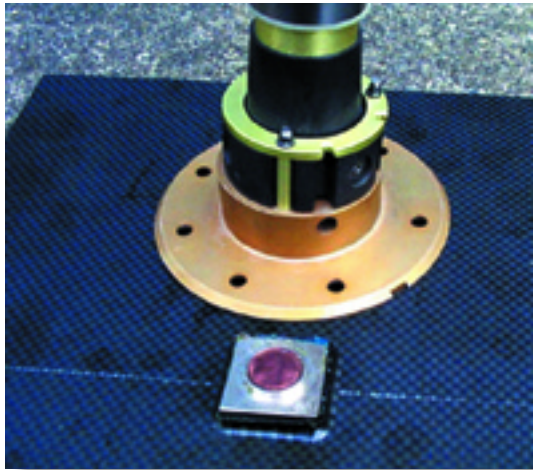


Figure 4. Ultrasonic Fuel Gauge/Damage Detector

have to build it, they understand what is required. We made decisions based on technical merit alone, with no political agenda. We used a simple design review process: If it wasn't working in the shop or in the test laboratory, we changed it at once (and documented the change later). And last but not least, we were not micro-managed by the higher authorities!

In the final analysis, the DFC program was a success for a very simple reason: it had a straightforward goal and a flexible approach. The program was allowed to proceed, develop, and change as needed to reach its goal of lighter, cheaper, and more survivable. That was the DFC program's recipe for success. ■

About the Author

Mr. Childress received his B.S. in Aerospace Engineering from University of Colorado, Boulder. The Boeing programs he has supported include the A-6, F/A-18, AV-8B, and V-22. In addition he has also supported programs with the ATF, F-22, JSE, A-X, Decoupled Fuel Cells, Composite Affordability Initiative, IR&D, Muzzle Blast, Advanced Composite Armor, Nitrogen Inflated Ballistic Bladder, z-pinned skin fusing, and various classified programs. He may be reached at James.Childress@PSS.Boeing.com.

MANPADS Study: A Brief Synopsis

by Mr. Joseph P. Jolley

Background

Shoulder-launched Man Portable Air Defense Systems (MANPADS) missiles rank as one of the most effective and economical anti-aircraft weapon systems in existence today. The infrared (IR) guided MANPADS threat, being highly mobile, hard to detect, and difficult to suppress, has influenced how aircraft are used in combat. Air commanders have become increasingly reluctant to conduct combat operations in low altitude battlespace, effectively relinquishing its use except in situations of absolute necessity. Avoidance is clearly the preferred option for surviving the MANPADS threat. However, this option is not always successful in combat. Aircraft continue to be hit by MANPADS. In a February 1998 memo, the Deputy Director Air Warfare, Strategic & Tactical Systems, Office of the Under Secretary of Defense, Acquisition and Technology, tasked the JTCG/AS to conduct a MANPADS study. The task was to collect and assess combat and test data to determine what advances may be achieved in vulnerability reduction that might mitigate aircraft losses or result in a reduced probability of kill.

Study Approach

The study was conducted in three phases—Phase I, the Data Collection phase, compiled data of interest related to encounters between MANPADS threats and aircraft. Phase II, the Data Analysis phase, included threat definition, an evaluation of vulnerability reduction techniques, and an assessment of vulnerability assessment methodologies. Phase III was Report Preparation. As part of the data collection phase, and to raise awareness of the importance of aircraft vulnerability to the MANPADS threat, a workshop was held in December 1998 at Huntsville, Alabama. Important considerations guiding the execution of this study were that:

- The needs of all Services be addressed

- Fighter, large transport, and rotorcraft air vehicles be addressed
- Industry input be included

Major Conclusions

Conclusion #1. While MANPADS are a highly lethal threat, MANPADS hits do not necessarily result in aircraft kills. Over 110 MANPADS combat incidents were reviewed, spanning several different conflicts. These data showed the probability of kill given a hit (PK/H), for aircraft hit by MANPADS, ranged from 0.5 - 0.8. While the PK/H varies as a function of aircraft type and specific threat, some aircraft platforms are more capable than others of surviving MANPADS hits.

Conclusion #2. Substantial deficiencies exist in data and analysis tools needed to improve aircraft vulnerability reduction design against the MANPADS threat. Results of the study revealed a lack of detailed understanding about MANPADS threat characteristics and damage mechanisms. Test data are required to better understand these phenomena.

Conclusion #3. Future advances in vulnerability reduction design, focused on the MANPADS threat, can best be achieved through incremental improvements and adaptation of existing techniques and technologies. Examples of possible opportunities to develop improved vulnerability reduction techniques against the MANPADS threat are in the areas of biasing MANPADS hit points away from flight-critical components, ultra-light weight armor techniques, and active fuze shielding concepts. Systematic progress, however, depends on solving the data and analysis deficiencies cited above.

Major Recommendations

Recommendation #1. Conduct MANPADS tests to gather data needed to characterize the threat, define damage and kill mechanisms, support development of vulnerability reduction techniques, and perform aircraft vulnerability assessments. Specific kinds of tests needed are; (1) Ground tests against actual aircraft to assess damage and kill mechanisms, (2) Fuzing and time delay tests, (3) Free field arena blast pressure tests,

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2000 calendar of events

MAR

20–24 — Fort Worth, TX
Joint Interim Mission Model (JIMM)
Contact: 937.431.2712, Paul Jeng

APR

24–27 — Dayton, OH
JMASS Conference and Users Group Sessions
Contact: 407.282.6400, John Davis

MAY

2–4 — Albuquerque, NM
Halon Options Technical Working Conference
Contact: 505.272.7250, Leanne Oliver

8–12 — University of Texas, Austin, TX
National Live Fire Test and Evaluation (LFT&E) Conference
Contact: 202.955.9472, Tracy Sheppard

16–18 — Wright Patterson AFB, OH
IAC Awareness and Business Meeting
Contact: 937.255.4840, Donna Egner

JUN

12–14 — Colorado Springs, CO
Space & Air Survivability Workshop 2000
Contact: 303.871.4502, Joel Williamsen
or 303.871.4049, Shirley Good

14–16 — Colorado Springs, CO
JTCCG/AS Model Users Meeting
Contact: 937.431.2712, Paul Jeng

20–22 — Virginia Beach, VA
Threats, Countermeasures, and Situational Awareness:
Teaming for Survivability
Contact: 812.854.3611, Norm Papke

NOV

13–16 — Monterey, CA
NDIA Aircraft Survivability Symposium
Contact: 703.247.2583, Joe Hylan

14–16 — Charlottesville, VA
BLUEMAX, ALARMS, and RADGUNS Users Group Meeting
Contact: 937.431.2712, Paul Jeng

28–30 — Nellis AFB, NV
BRAWLER Users Group Meeting
Contact: 937.431.2712, Paul Jeng

28–30 — Nellis AFB, NV
EJAMS Users Group Meeting
Contact: 937.431.2712, Paul Jeng

Information for inclusion in the
Calendar of Events may be sent to:

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FAX: 703.289.5467

MANPADS Study

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(4) Confined bay blast and damage tests, (5) Warhead fragment and missile body characterization arena tests, and (6) Propellant effects tests. To the extent possible, data should be captured in a centralized database accessible to analysts, designers, testers, and intelligence agencies.

Recommendation #2. Develop improved aircraft-MANPADS modeling methodologies. Methodologies must provide information on target acquisition, hit-point prediction, and vulnerability assessment.

Recommendation #3. Investigate promising technology areas for new vulnerability reduction techniques against MANPADS, including cost-benefit assessments. Areas for advancement include, hit-point biasing, light-weight armor, and shielding. Concepts should have application to major redesigns of systems as well as new designs, and address the needs of fighter, large transport, and rotorcraft platforms.

Recommendation #4. Develop an Aircraft MANPADS Survivability Design Guide. The guide should include synopses of validated vulnerability reduction features and relative advantages and limitations of each feature. The

guide should be structured for program managers as well as design engineers.

Summary

In summary, the study highlighted the fact that MANPADS are a serious worldwide threat to which the military aviation community must give increased emphasis. Improved vulnerability reduction techniques are achievable, and will result from innovative application of the current knowledge base in vulnerability reduction design. However, deficiencies in data and analysis tools must be remedied.

Future air combat operations will continue to face a MANPADS threat. Assuring the optimal combination of vulnerability reduction and susceptibility reduction characteristics early in the design of new aircraft, or major upgrades, will allow aircraft to better withstand MANPADS hits, minimize operational risk, and help regain lost battlespace. ■

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